Effects of Air Emissions Externalities on Optimal Ride-Hailing Fleet Electrification and Operations

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June 2020

Ride-hailing is transforming transportation

- **Transportation** is now the largest source of U.S. GHGs
    - Primarily from passenger cars[1]
- **Ride-hailing** services by transportation network companies (TNCs) like Uber & Lyft are rapidly changing the passenger car landscape
    - Share of passenger trips in for-hire vehicles doubled in last decade[2]
    - 15% of intra-urban trips in San Francisco were served by Uber and Lyft (2016)
- **Electrification:** IPCC states passenger transportation must be electrified by 2035-2050 to limit warming to 1.5C[3]

1: US EPA, Office of Atmospheric Programs (2017). Inventory of U.S. greenhouse gas emissions and sinks, 1990-2016.
2: Conway, M., Salon, D., & King, D. (2018). Trends in Taxi Use and the Advent of Ridehailing, 1995–2017: Evidence from the US National Household Travel Survey. *Urban Science*, *2*(3), 79.
3: *Intergovernmental Panel on Climate Change: Global Warming of 1.5 °C: An IPCC special report. (2018)*
Cover slide image: Fleet Carma: “Electric Taxis Are On Their Way”. <www.fleetcarma.com/electric-taxis-on-their-way/>

Electrify ride-hailing fleets?

+ **Pros of Electric Vehicles (EVs)**
Lower variable costs of fuel/energy
Potential to reduce emissions
Natural fit for urban driving

− **Limitations of EVs**
Higher fixed cost
Vehicles recharging can’t serve trips
Recharging adds empty vehicle miles

Research questions

1. What technology mix is optimal for ride-hailing fleets?
2. How does internalizing externalities change optimal ride-hailing fleets?
3. How do location and model assumptions affect these results?

Background

Data & Methods

Results

Summary

Approach

Supply-side

- Find optimal mix of vehicle technologies (conventional, hybrid, and battery electric) and operations to minimize cost
- Study how result changes under Pigovian tax, location, and alternative assumptions

Demand side

- Exogeneous based on past trip data. Must be satisfied.
- Ideally would be equilibrium with demand elasticities, but difficult to credibly (and tractably) model substitution traveler mode choice and trip shedding in response to pricing
- More later

A network of arcs models fleet investment and dispatch

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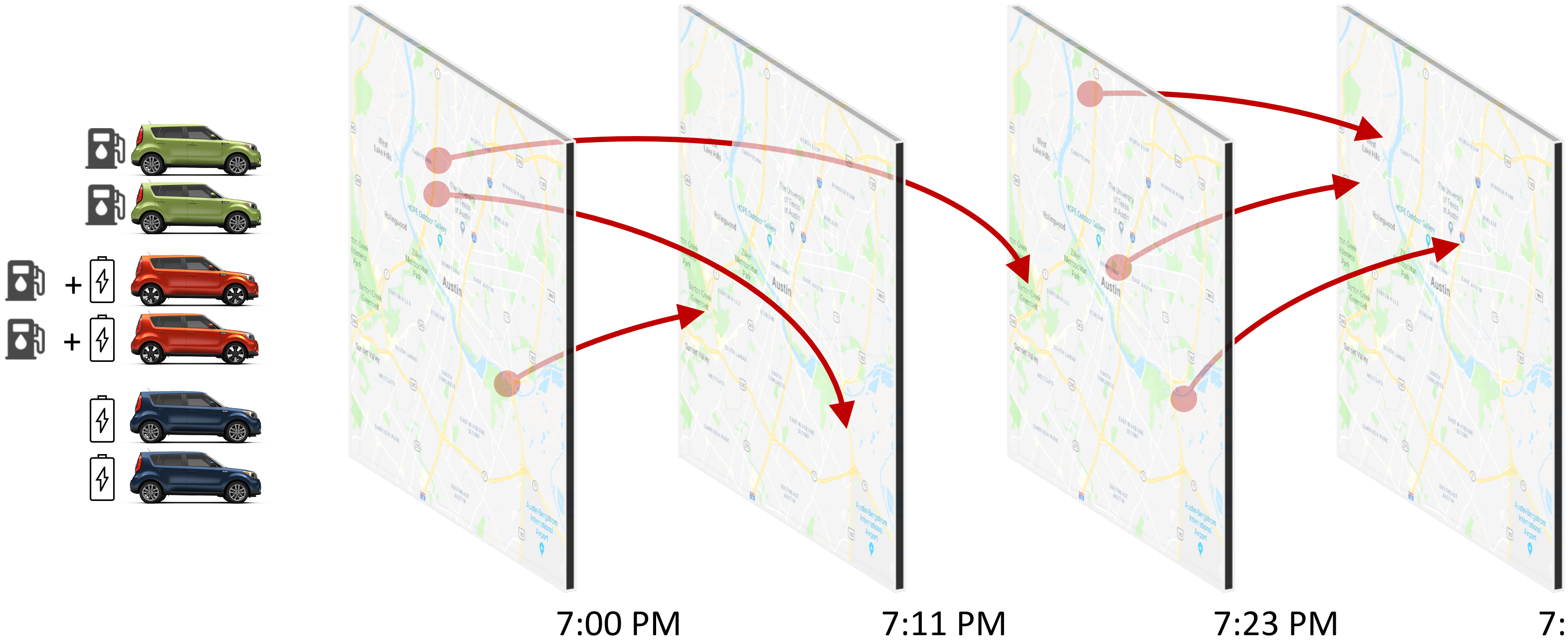
Which cars should the fleet purchase? 6 cars = 6 decisions

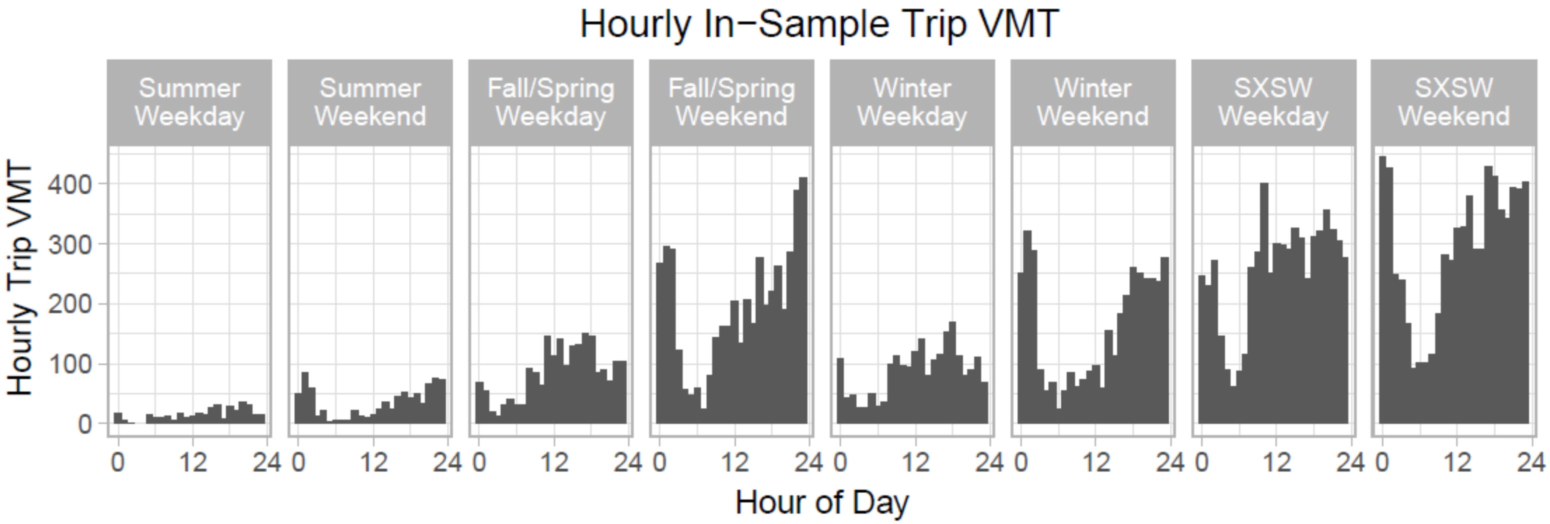
A network of arcs models fleet investment and dispatch



Which cars should the fleet purchase? 6 cars = 6 decisions

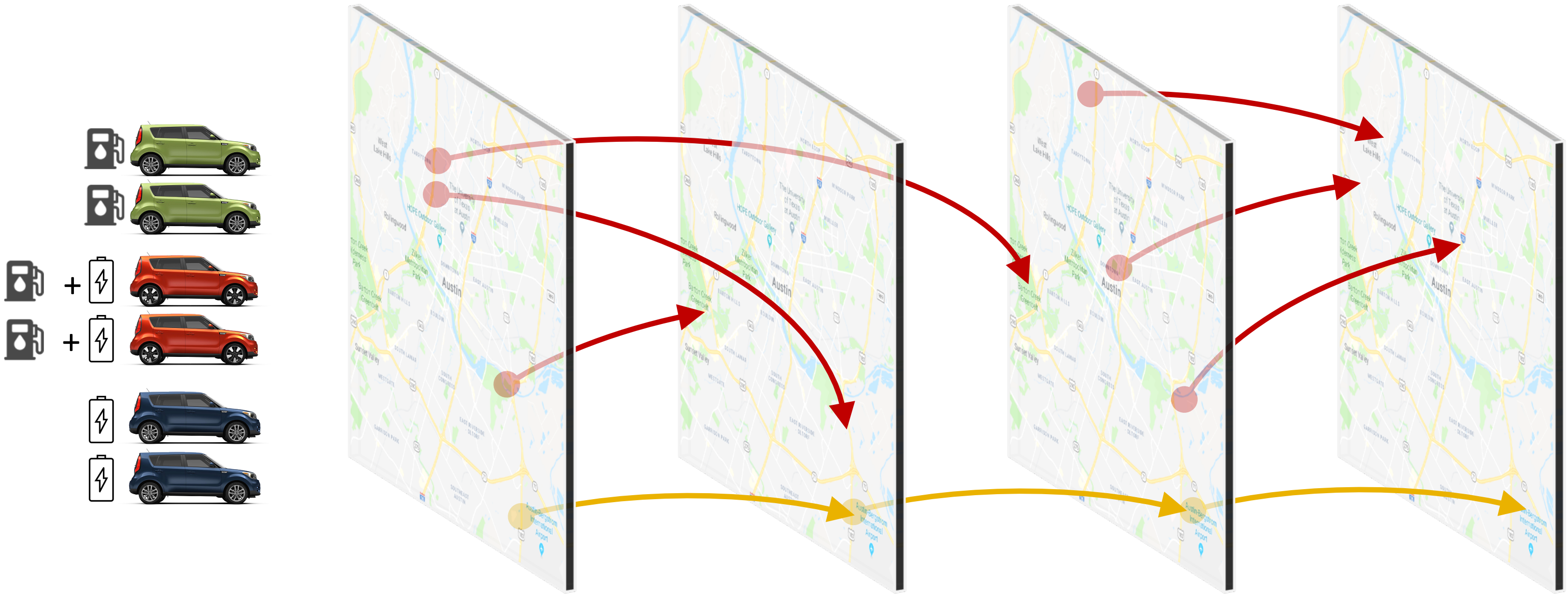
Which car should serve each **trip request**? 6 cars x **6 trips** = 36 decisions

We use a sample of ride-hailing trips from RideAustin and modify cost inputs for Austin, LA, and NYC



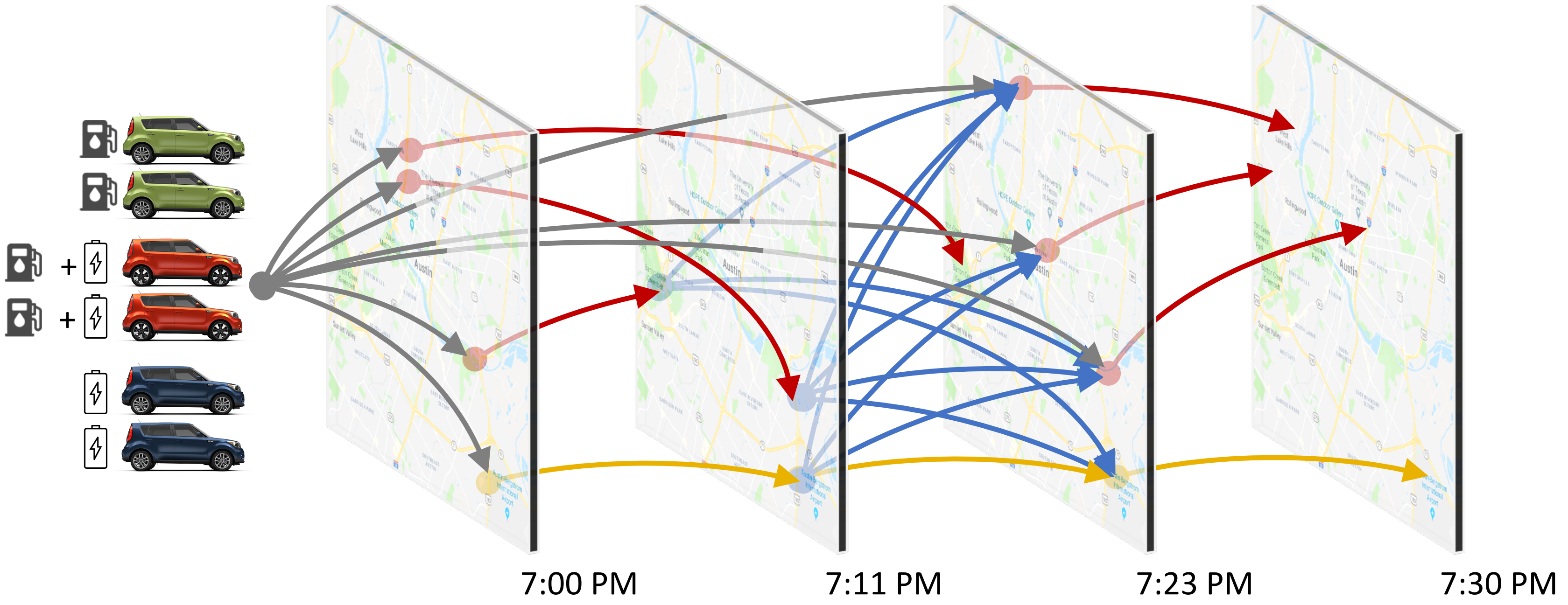
- RideAustin operated as a near-monopoly when Uber/Lyft left Austin
- We sample 5,000 representative RideAustin trips out of 1.5 million total
- To model Los Angeles and NYC, we change:
  - Electricity and gasoline prices
  - eGrid subregion of marginal emission factors
  - Counties of oil refinery and tailpipe emissions damages

A network of arcs models fleet investment and dispatch



Which cars should the fleet purchase?	6 cars	= 6 decisions
Which car should serve each **trip request**?	6 cars x **6 trips**	= 36 decisions
When should each battery EV **charge**?	6 cars x **3 charge timeslots**	= 18 decisions

A network of arcs models fleet investment and dispatch



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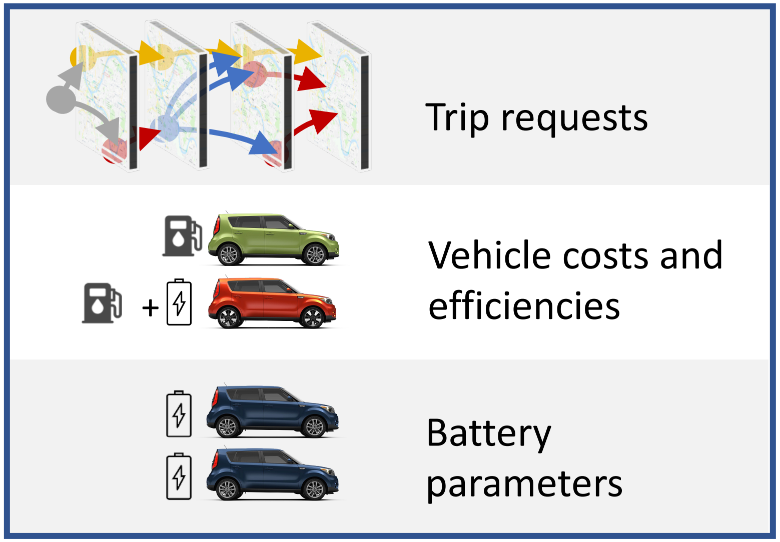
When should each battery EV **charge**?	6 cars x	**3 charge timeslots**	= 18 decisions
Which **dispatches** and **connections** between trips minimize costs?	6 cars x	**22 arcs**	= 132 decisions

Model summary

Find fleet technology mix and operations
to minimize cost (capital, energy, maintenance, externalities)
subject to satisfying exogeneous trip demand

Inputs

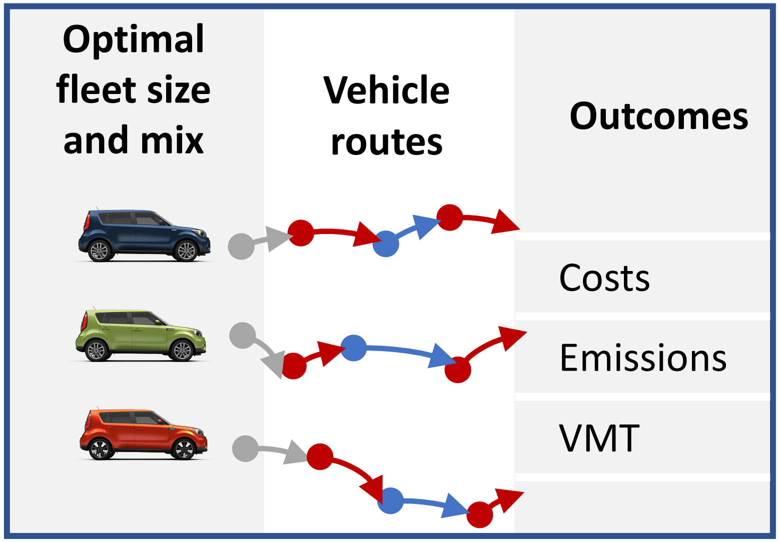


Trip requests

Vehicle costs and efficiencies

Battery parameters

Outputs



Optimal fleet size and mix

Vehicle routes

Outcomes

Costs

Emissions

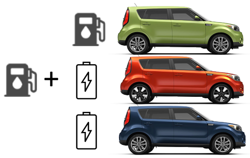
VMT

Compare results with and without a Pigovian tax on
air emission externalities (SCC, APEEP3, InMAP, EASIUR)* **

*other externalities unaffected by technology change;
**supply chain treated as though Pigovian tax is passed through

Mixed-integer linear programming optimizes fleet investments and dispatch

Vehicles $k \in K$



Network L (source *r* to sink *s*)

- Arcs *(i,j)* from node *i* to *j*
- Demand $d_{i,j}$
- Variable cost $v_{k,i,j}$
- Energy change $e_{k,i,j}$
- Electricity price g_t at time *t*

Decisions *X*

- Assignments $a_{k,i,j}$
- Vehicle charge $l_{k,t}$ at time *t*
- Charger usage $c_{k,t}$
- # of purchases p_k for car k
- Annualized distance d_k
- Annualized capital costs h_k

Objective

$$\underset{\mathcal{X}}{\text{minimize}} \sum_{k\in\mathcal{K}} h_k + \sum_{(i,j)\in\mathcal{A}} a_{k,i,j} v_{k,i,j} + \sum_{k\in\mathcal{K}} \sum_{t\in\mathcal{T}_+} c_{k,t} g_t$$

Minimize costs of capital, energy and maintenance

Constraints (1/2)

$$\sum_{i\in\mathcal{V}} a_{k,i,j} = \sum_{i\in\mathcal{V}} a_{k,j,i} \quad \forall k \in K, j \in \mathcal{V}\setminus\{r,s\}$$

Network flow conservation

$$\sum_{k\in\mathcal{K}} a_{k,i,j} = n_{i,j} \quad \forall (i,j) \in \{\mathcal{A} : n_{i,j} > 0\}$$

Passenger demand is met

$$\sum_{j\in\mathcal{V}\setminus r} a_{k,r,j} = p_k \quad \forall k \in \mathcal{K}$$

Vehicles must be purchased in order to be used

$$\sum_{(i,j)\in\mathcal{A}} m_{i,j} = d_k \quad \forall k \in \mathcal{K}$$

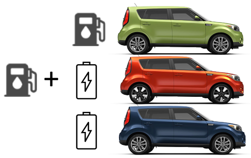
Each vehicle's usage is tracked

$$\begin{aligned} h_k &\geq p_k \gamma_k && \forall k \in \mathcal{K} \\ h_k &\geq p_k \delta_{1,k} + d_k \zeta_{1,k} && \forall k \in \mathcal{K} \\ h_k &\geq p_k \delta_{2,k} + d_k \zeta_{2,k} && \forall k \in \mathcal{K}_B \end{aligned}$$

Each vehicle's capital cost increases with usage

Mixed-integer linear programming optimizes fleet investments and dispatch

Vehicles $k \in K$



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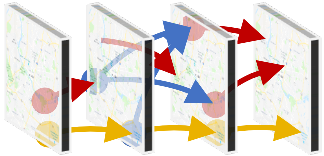

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- Demand $d_{i,j}$
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Decisions *X*

- Assignments $a_{k,i,j}$
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- # of purchases p_k for car k
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Objective

$$\underset{\mathcal{X}}{\text{minimize}} \sum_{k\in\mathcal{K}} h_k + \sum_{(i,j)\in\mathcal{A}} a_{k,i,j} v_{k,i,j} + \sum_{k\in\mathcal{K}} \sum_{t\in\mathcal{T}_+} c_{k,t} g_t$$

Minimize costs of capital, energy and maintenance

Constraints (2/2)

$$c_{k,t} = l_{k,t+1} - l_{k,t} + \sum_{(i,j)\in\{\mathcal{A}: t_i = t, e_{k,i,j}<0\}} a_{k,i,j} e_{k,i,j} \quad \forall k \in \mathcal{K}_B, t \in \mathcal{T}_+$$

Charger usage is calculated

$$l_{k,t+1} \leq l_{k,t} + \sum_{(i,j)\in\{\mathcal{A}: t_i = t\}} a_{k,i,j} e_{k,i,j} \qquad \forall k \in \mathcal{K}_B, t \in \mathcal{T}_+$$

Charge level rises/falls (timesteps with a charge timeslot)

$$l_{k,t+1} = l_{k,t} + \sum_{(i,j)\in\{\mathcal{A}: t_i = t\}} a_{k,i,j} e_{k,i,j} \qquad \forall k \in \mathcal{K}_B, t \in \mathcal{T} \setminus \mathcal{T}_+$$

Charge level rises/falls (timesteps with no charge timeslot)

$$0 \leq l_{k,t} \leq b_k \qquad \forall k \in \mathcal{K}_B, t \in \mathcal{T}$$

Charge level is bounded by battery capacity

$$a_{k,i,j} \in \{0,1\},\ p_k \in \{0,1\} \qquad \forall k \in \mathcal{K}_B, (i,j) \in \mathcal{A}$$
$$a_{k,i,j} \in \mathbb{Z}_+,\ p_k \in \mathbb{Z}_+ \qquad \forall k \in \mathcal{K} \setminus \mathcal{K}_B, (i,j) \in \mathcal{A}$$

Purchases and assignments are integral

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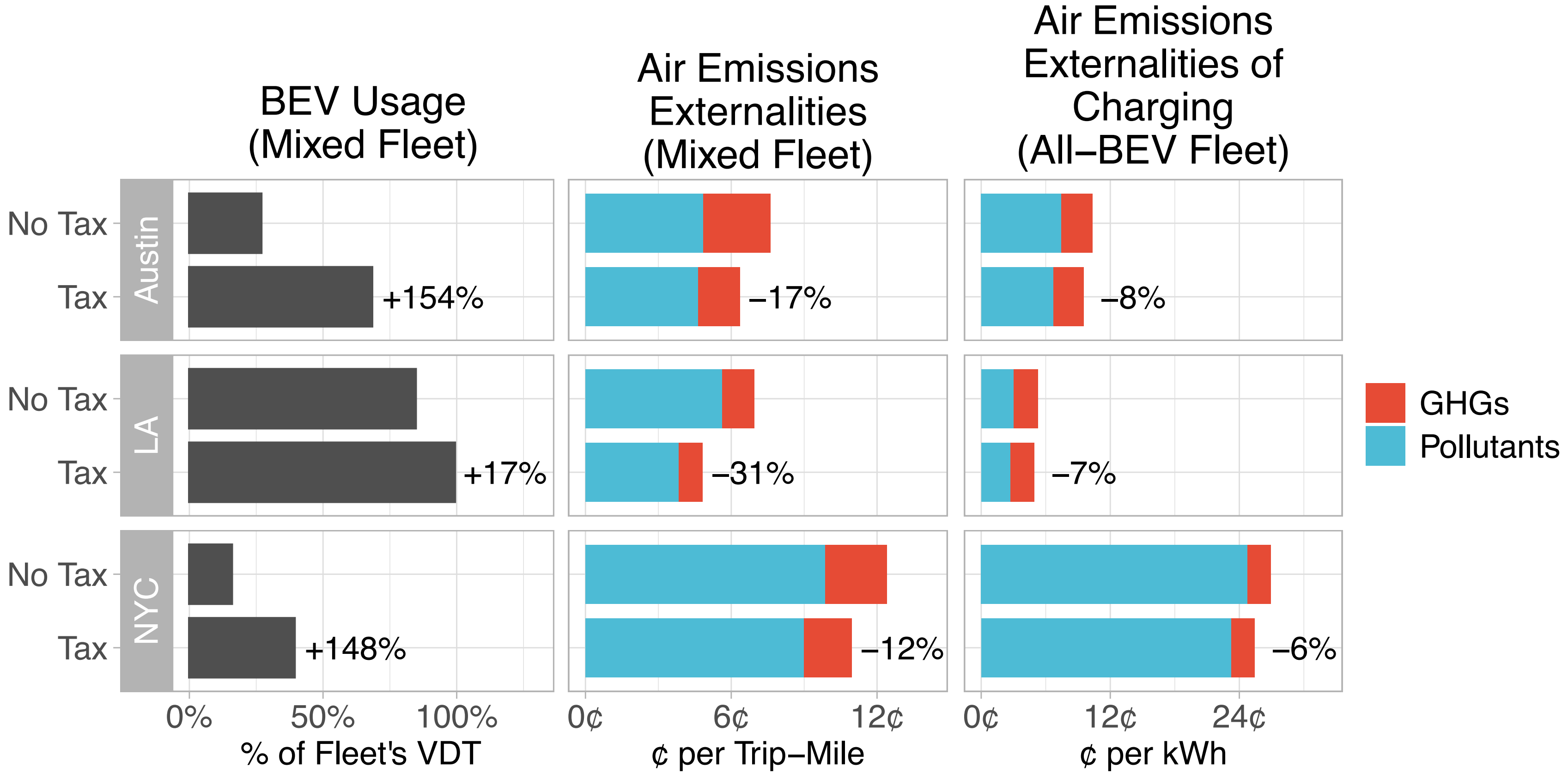
Pigovian Tax on Air Emission Externalities →

- greater electrification
- cleaner charge timing
- lower emissions



In present-day scenarios, taxing emissions always increases electrification, but the size of the shift varies widely

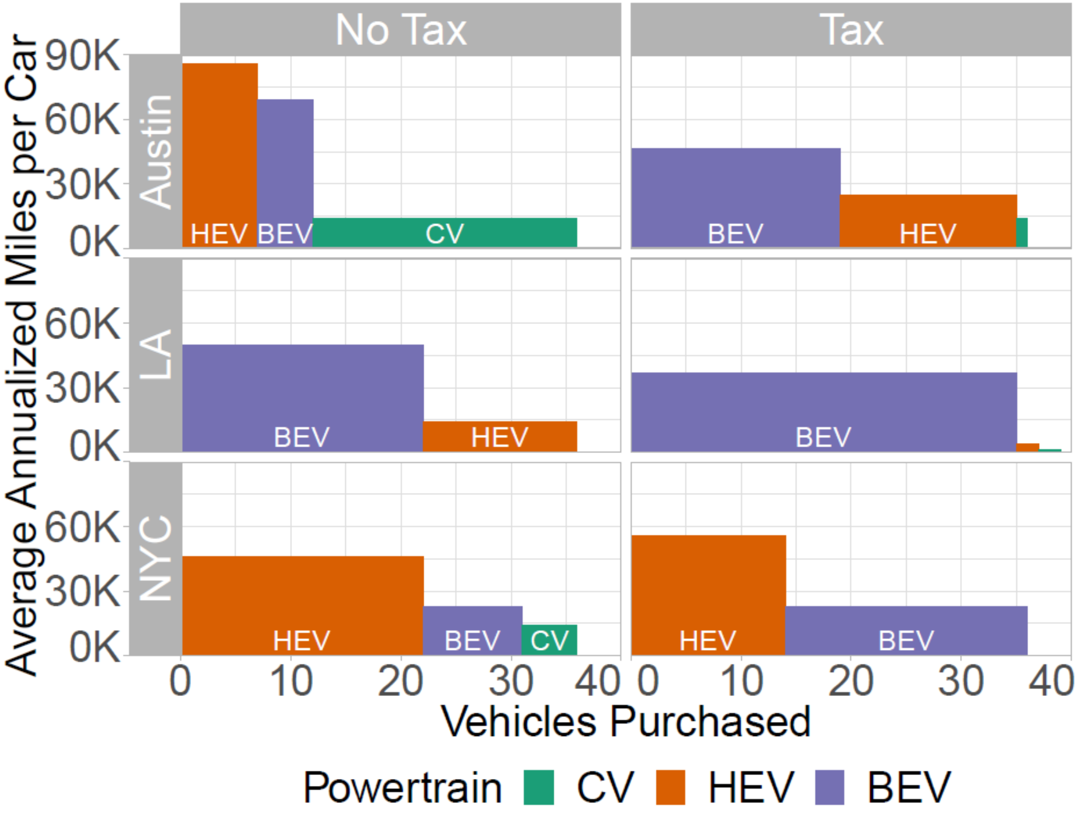
Austin, TX:

- A status-quo fleet purchases a majority of CVs and uses each HEV most heavily
- When taxed, the fleet purchases a majority of BEVs and uses them most heavily

Los Angeles: a tax increases an already-large degree of electrification

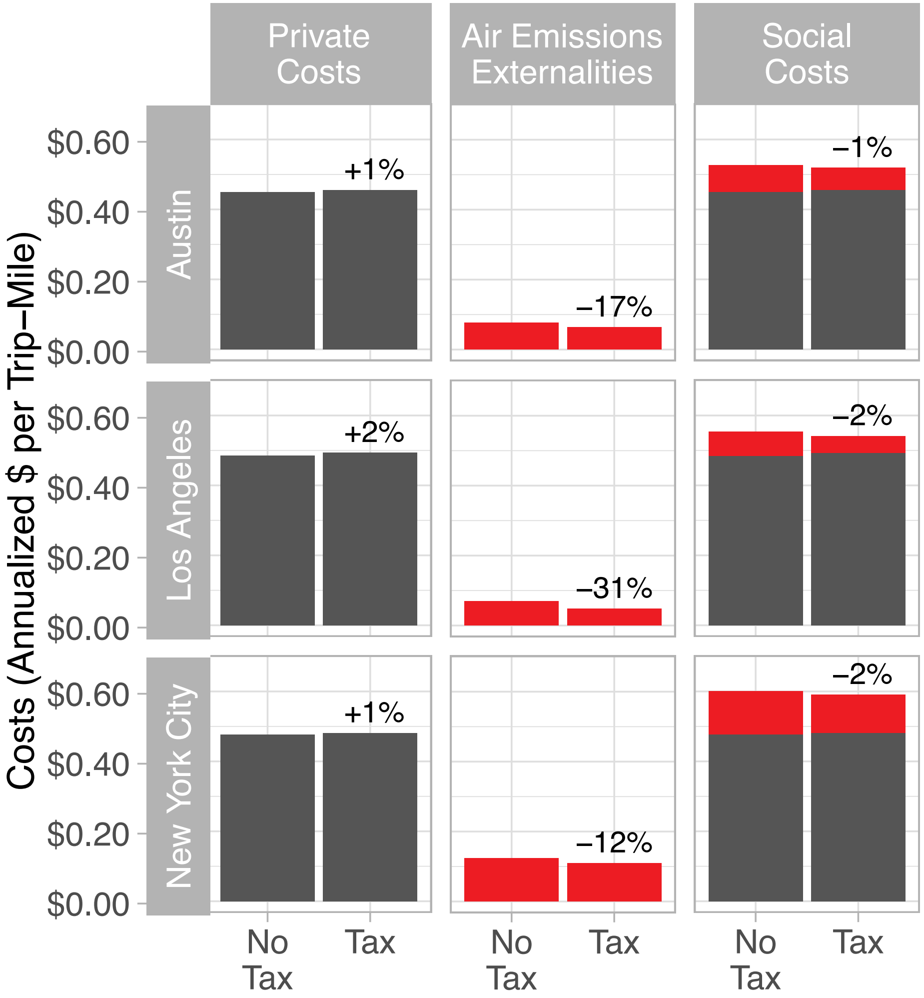
NYC: a tax increases HEV usage and BEV purchases while eliminating CVs

Pigovian tax's impact on
each powertrain's purchases and usage



Emissions externalities can be reduced by 12-31% while increasing private costs 1-2%

- Across cities, imposing a Pigovian tax has little impact (1-2%) on the private costs of purchasing and operating the fleet
- The tax reduces health and climate change externalities by 12-31%, depending on city
  - ~$30M/yr in LA
- The net efficiency gain (social costs) is small, but the effect on air emission externalities is significant



Sensitivity analysis

Key results robust across sensitivity scenarios; magnitude varies

- Externality valuation assumptions
  - Air pollution, GHGs
- Discount rate
- Labor costs
- Resale salvage value assumptions
- Vehicle cost, battery capacity
- Homogeneous fleets

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Pigovian tax on air emission externalities results in

- Increased vehicle electrification (17%-154%)
- Reduced air emission externalities (12%-31%)
- Small change in social welfare, but significant effect on air emission externalities - ~$30M/yr in LA

Suggests a role for policy. However, blunt instruments favoring one technology over another may not be desirable

- Socially optimal fleet is a mix of technologies
- Socially optimal fleet varies by location and other factors that change over time

In context

We model a central decision-maker minimizing cost with perfect information of exogeneous demand

- Ignores market mechanisms (pricing, competition)
- Might approximate Uber/Lyft to the extent that…
  - TNCs lease vehicles to drivers for TNC driving
  - drivers respond to incentives about when to drive
  - good demand forecasting
  - fleet-wide regulation induces coordination (CA Clean Miles Standard)
- Likely better approximation of a future autonomous fleet
- Perfect information may overestimate ability to optimally schedule BEVs in particular

In context

We apply a life cycle Pigovian tax to the TNC

- In practice, supply chain would adjust
- Market power: pass-through to consumers would shift demand to other modes

We ignore dual use

- Overestimates the cost-saving potential of conventional vehicles for peak demand (but mitigated by salvage value)

Acknowledgments

- Carnegie Mellon Center for Climate and Energy Decision Making, National Science Foundation
- Center for Air, Climate, and Energy Solutions (CACES), U.S. Environmental Protection Agency
- Scott Institute for Energy Innovation
- Extreme Science and Engineering Discovery Environment (XSEDE), National Science Foundation